

## Improving the Sound Absorption Properties of Flexible Polyurethane (PU) Foam using Nanofibers and Nanoparticles

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**Abstract:** Polyurethane foam as the most well-known absorbent materials has a suitable absorption coefficient only within a limited frequency range. The aim of this study was to improve the sound absorption coefficient of flexible polyurethane (PU) foam within the range of various frequencies using clay nanoparticles, polyacrylonitrile nanofibers, and polyvinylidene fluoride nanofibers. The response surface method was used to determine the effect of addition of nanofibers of PAN and PVDF, addition of clay nanoparticles, absorbent thickness, and air gap on the sound absorption coefficient of flexible polyurethane foam (PU) across different frequency ranges. The absorption coefficient of the samples was measured using Impedance Tubes device. Nano clay at low thicknesses as well as polyacrylonitrile nanofibers and polyvinyl fluoride nanofibers at higher thicknesses had a greater positive effect on absorption coefficient. The mean sound absorption coefficient in the composite with the highest absorption coefficient at middle and high frequencies was 0.798 and 0.75, respectively. In comparison with pure polyurethane foam with the same thickness and air gap, these values were 2.22 times at the middle frequencies and 1.47 times at high frequencies, respectively. Surface porosity rose with increasing nano clay, but decreased with increasing polyacrylonitrile nanofibers and polyvinyl fluoride nanofibers. The results indicated that the absorption coefficient was elevated with increasing the thickness and air gap. This study suggests that the use of a combination of nanoparticles and nanofibers can enhance the acoustic properties of flexible polyurethane foam.

**Keywords:** Sound absorption coefficient; flexible polyurethane foam; nano clay; polyacrylonitrile nanofibers; polyvinyl fluoride nanofibers

## 1 Introduction

Noise pollution has a wide range of undesirable health- and non-health-related effects [1]. With the development of new technologies, in particular the development of faster and more powerful devices, concerns have been raised over noise pollution and many efforts have been made to effectively control this kind of pollution [2, 3]. Accordingly, the subject of noise has become a serious and complex problem, and the need for research in this field has increased for a better life and working environment [4], which has prompted researchers to work on controlling noise. There are various mechanisms for controlling and reducing noise levels, each of which is used at a specific level and situation. The use of porous sound absorbing material in the passageway of noise is one of the very effective methods of noise control [5]. In general, sound absorbing materials are used to reduce the reflection of sound from hard surfaces [6, 7].

When the sound enters a porous structure, it changes into heat due to friction whereby it loses its energy [4]. Polymer porous absorbents, such as polyurethane, polyacrylic ester, polystyrene and polyvinyl chloride, are widely used as sound absorbents, which are mostly prepared in the form of polymer foams. These materials are useful in sound absorption, but to improve their sound properties, their structure should be modified [8].

Acoustic foams are used to minimize the reflection of sound in music rooms, studios, cinemas, and other places with polyurethane foam being one of the materials which is often used to control the sound [9]. Polyurethane foam is one of the absorbing materials with many advantages, including light weight, low absorption, and low cost [10]. This foam is known as an absorbent with a relatively good absorption coefficient [11]. Two mechanisms should be considered in the sound absorption by polyurethane foam: the absorption of sound energy through friction between gaseous molecules fluctuating in the space of porous foam cavities and their kinetic energy converting to heat. In this mechanism, the cavities play an important role in absorbing the sound energy. The second mechanism relates to the wall material of the pores; sound absorption in this mechanism occurs through the intrinsic damping of the system. In this mechanism, sound waves propagate inside the material [11]. Accordingly, the absorption coefficient of foam materials depends on their structural properties [12].

It is very difficult to control the pore size and distribution of cell structures as porous structures are produced by randomly distributed pore-constituting particles. Meanwhile, additive manufacturing technology has advantages in designing open-cell structures [13, 14]. In recent years, sound control has been of interest to researchers, especially at low frequencies where important innovations have occurred in sound control technology such as active noise cancellation systems [15, 16] and sound absorbing structures [17, 18], which have gained popularity in recent decades. One of the important sound control technologies is modifying materials using nanotechnology, which has proved effective over wide bandwidths for sound control.

Nanotechnology has also been widely used over the past several years for its unique features. Nanofibers and nanoparticles, due to their high surfaces area, cause the sound wave to be entrapped, whereby the sound energy is dampened. The acoustic behavior of nanomaterials and nanofibers has remained understudied. Accordingly, this research tried to determine the acoustic behavior of polyurethane foam containing nanofiber and nanoparticles along with the absorption behavior of these materials in polyurethane foam. The major purpose of this study was to improve the absorption properties of flexible polyurethane foam (PU) with nano clay, polyacrylonitrile nanofibers (PAN NF), and polyvinyl fluoride nanofibers (PVDF NF).

## 2 Method

### 2.1 Study Design

Determining optimal levels through traditional methods is time-consuming and requires countless tests. In addition, in traditional methods, the combined effects of all factors affecting the response variable are not

considered. The Response Surface Methodology (RSM) technique is a blend of statistical and mathematical methods and is suitable for situations where several independent operating parameters affect one response variable, through which one can evaluate the importance of factors affecting the response variable by providing an experimental design [19]. In this study, to determine the effect of nano clay, PAN NF, PVDF NF, thickness, and air gap on the absorption coefficient of PU within the middle (500-1250 Hz) and high (1600-6300 Hz) frequencies via the, Expert Design (Version 7, Stat-Ease, Minneapolis) was used. Parameters of PAN NF% (1-2%), PVDF NF% (1-2%), nano clay % (1-2%), thickness (0.5-2.5 cm), and air gap (0-2 cm) were considered as input variables.

## **2.2 Materials**

Montmorillonite nano clay was obtained from Sigma-Aldrich Chemie GmbH, Iran, with CAS-No: 1318-93-0. Bulk density=350kg/m<sup>3</sup>. The diameter of the clay nanoparticles was 1-2 nm. The other materials used were as follows: Polyol with MDI system under HR-338 code and Isocyanate under code 8001 Mokarrar Engineering Materials Co Polyacrylonitrile material MW = 80000 g/mol Polyacrylic company Isfahan, PVDF Flurine Company with a molecular weight of 260,000 Dalton, Dimethylformamide solvent with a molecular weight MW = 73.1 g/mol Made by Merck with CAS-No:68-12-2, acetone solvent with molecular weight MW = 58.08 g/mol from Majallali company with CAS-No:67-64-1, solvent N,N-Dimethylacetamide (DMAc) weight MW = 87.12 g/mol from Merck Co. with CAS-No: 127-19-5.

## **2.3 Production of Nanocomposites**

To prepare a solution of PAN, DMF solvent with 10% wt PAN powder and 90% DMF solvent were used. They were placed on stirrer at a temperature of about 40 to 50 °C for 10 to 12 hours, until the granules were completely dissolved, and a clear, uniform fluid was obtained. The PAN solution was then poured into an electrospinning reservoir manufactured by the Fanavaran Nano-Meghyas Company. The positive voltage level was 26 V and the negative voltage was -25 V. The distance between the dissolved pond and the foil was 13 cm in diameter and the ambient temperature was 30 ± 5 °C, whereby electrospinning was carried out. To prepare the PVDF solution, a 70/30 ratio of DMAc and acetone solution was used. For preparing the volumetric percentage of 30% PVDF polymer solution, PVDF polymer granules were first dissolved in DMAc 70% and placed for 10-12 hours on a stirrer at a temperature of about 40 to 50 °C until the granules were completely dissolved and a clear, uniform fluid was produced. Then, before usage for electrospinning, the solution was allowed to cool and then 30% volumetric/volumetric acetone was poured into solution and then again stirred for 20-30 minutes on a non-thermal stirrer. Electrospinning device manufactured by Fanavaran Nano-Meghyas Company, through injectable electrospinning method was used to produce PVDF NF. The volumetric weight ratio of PVDF granules, DMAc and acetone solvents was determined with a ratio of 70/30, distance between the syringe end and collector of 15 cm, voltage of 10 kV, and injection rate of 1 cc/hr via electrospinning. In order to make the desired composites, according to the test runs, PVDF NF and PAN NF were added to the polyol prepared with the MDI system. Then, the polyol containing the nanofibers was stirred for 2 hours plus 30 minutes with ultrasound to propagate the homogeneous nanofiber inside the polyol. Nano clay was then poured inside the isocyanate and stirred for 2 hours and then homogeneously dispersed in ultrasonic system for 30 minutes. Ultimately, polyol containing PAN NF and PVDF NF with isosaccate containing clay nanoparticles was poured into the mold and mixed using a mechanical stirrer and finally molded to form the desired composites.

## **2.4 Measurement of Acoustic and Physical Properties**

The best method for measuring the sound absorption coefficient is to use the Wave Standing Method. In this method, special tubes are used which can be used to obtain the normal absorption coefficient of the

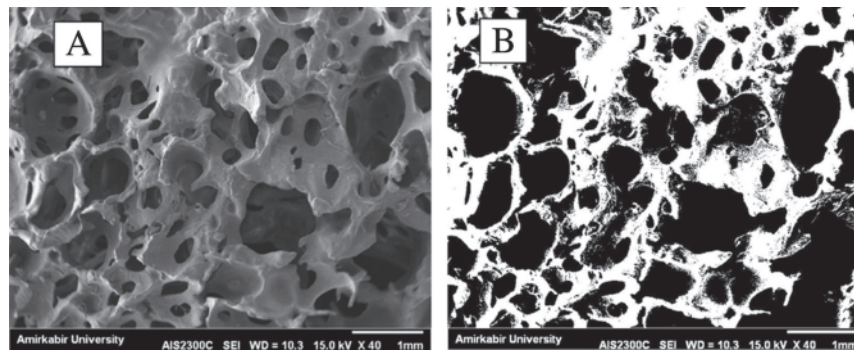
material. In the method of standing wave tube, the absorbent material is placed at the end of the tube and there is a loudspeaker at the beginning. Within the tube, the sound waves are released by the loudspeaker and strike the sample of absorbent material vertically at the end of the tube and reflect away. Accordingly, the absorption coefficient measured in this method is called the normal absorption coefficient. Returning waves were measured by the microphone [20]. In this study, BSWA SW477 550005 was used to measure the absorption coefficient based on ISO10534-2 standard [21]. To measure the Young Pressure modulus, the SANTAM device at 50 mm/min was utilized according to the ASTM D3574 standard [22]. Fig. 1 demonstrates the tube impedance device used to measure the sound absorption coefficient.



**Figure 1:** Tube impedance device to measure the sound absorption coefficient

### 2.5 Determination of Morphology

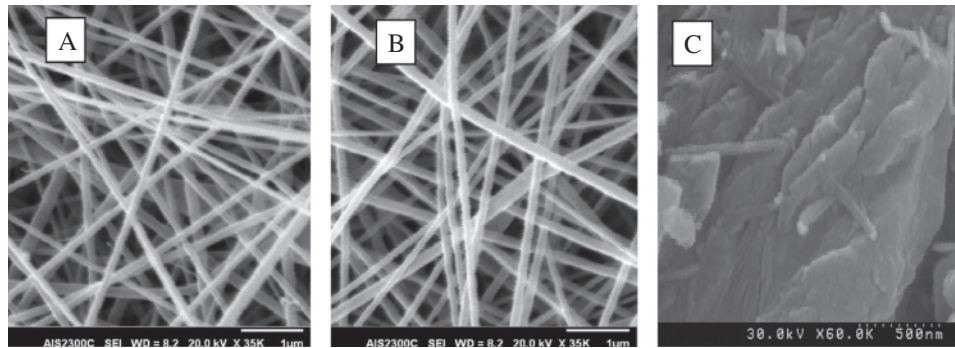
In order to measure the mean diameter of the fibers, the Image J image analysis software was used. Images of the scanning electron microscope were taken from the surface of the fibers. Then, the software selected 20-30 fibers from each photo and finally calculated their average diameter. SEM image analysis algorithms were used to calculate the porosity percentage of composites using (MathWorks, Version7 (MATLAB software [23]). In this technique, the input element is a two-dimensional binary image that generates these binary images through the overall threshold method with the creation of black and white images, and uses a fixed threshold for image partitioning. The binary image (black and white) is called an image which is all white or black. The porosity of the composites was determined based on blackness of 0 and whiteness of 255. The initial examination of SEM images was considered as porosity values below 100. Fig. 2 displays a sample of images. Data were analyzed using Expert Design software [24]. Models which were developed separately through the software for each frequency range were obtained, while some items whose omission increased the validity of the model were deleted.



**Figure 2:** A: SEM image, B: Composite binary image

### 3 Results and discussion

Figure 3 exhibits the electrospinning nanofibers and the nano clay used in the composites. The diameters of PAN NF, PVDF NF, and clay nanoparticles were  $85 \pm 20$  nm,  $96 \pm 20$  nm, and 1-2 nm, respectively.



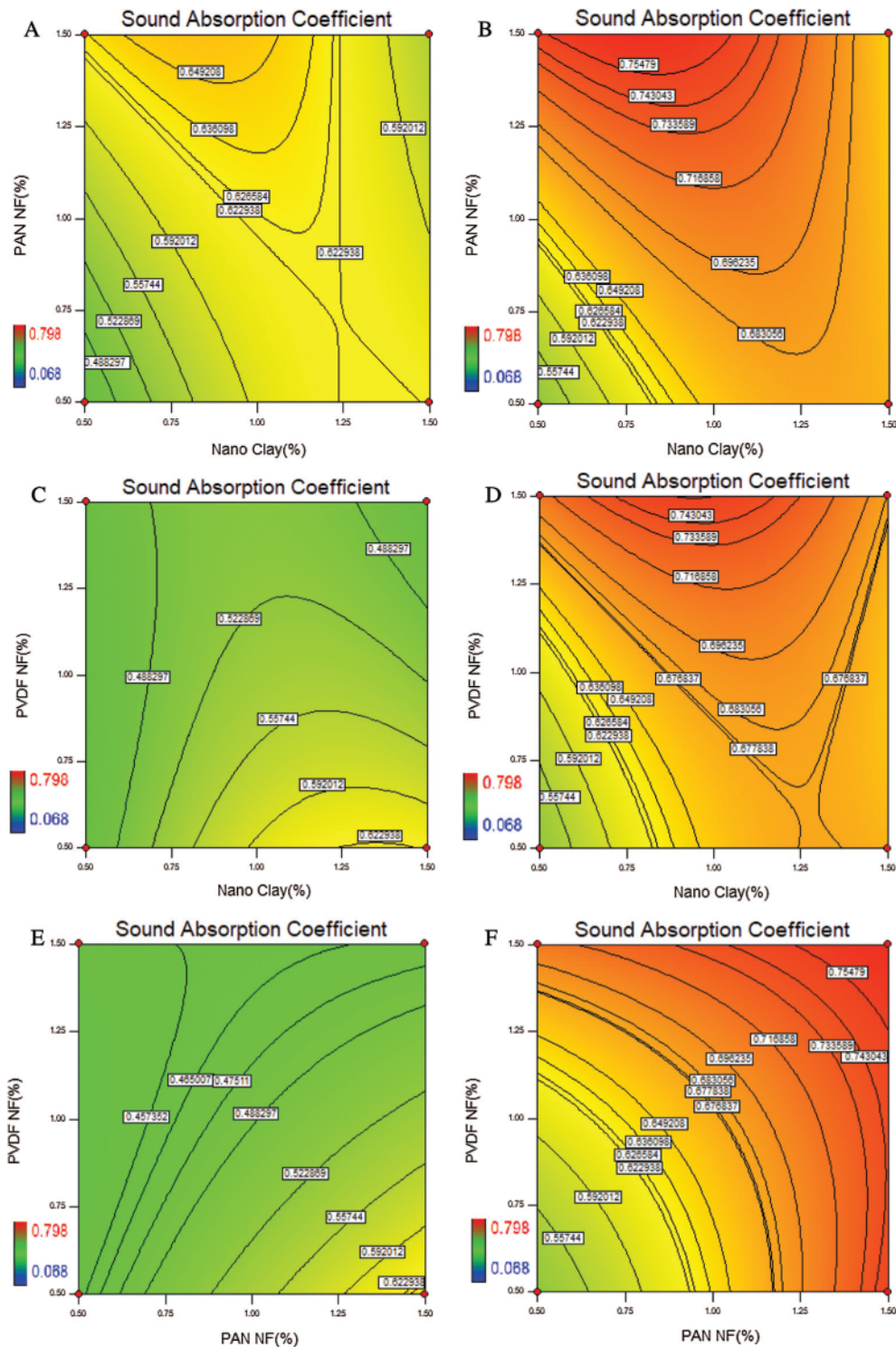
**Figure 3:** The shape of nanoparticles and nanofibres used in nanocomposites A: PAN NF B: PVDF NF C: Nano Clay

According to Figs. 4 and 5, nanoclay particles, PAN NF, and PVDF NF have had a greater effect on the sound absorption coefficient at middle frequencies than at high frequencies. Due to the fact that the RMS part in Design Express software eliminates the upper and lower limits, in order to investigate the effect of independent variables in different thicknesses, 1 cm Thickness and 2 cm Thickness are adopted as representatives of low and high thicknesses, respectively. A study conducted by Nor et al. to investigate various factors on sound absorption coefficient of coir fiber showed that by decreasing the size of coir fiber, the absorption coefficient increased at low frequencies [25]. A study conducted by Buyukakinci et al. to study the acoustic properties of natural fibers mixed with PU composite suggested that the increase in flax fiber enhanced absorption at low frequencies [26]. Previous and current studies have shown that the use of fibers, and in particular the finer fibers, yield a greater effect on increasing the absorption coefficient at low frequencies compared to high frequencies.

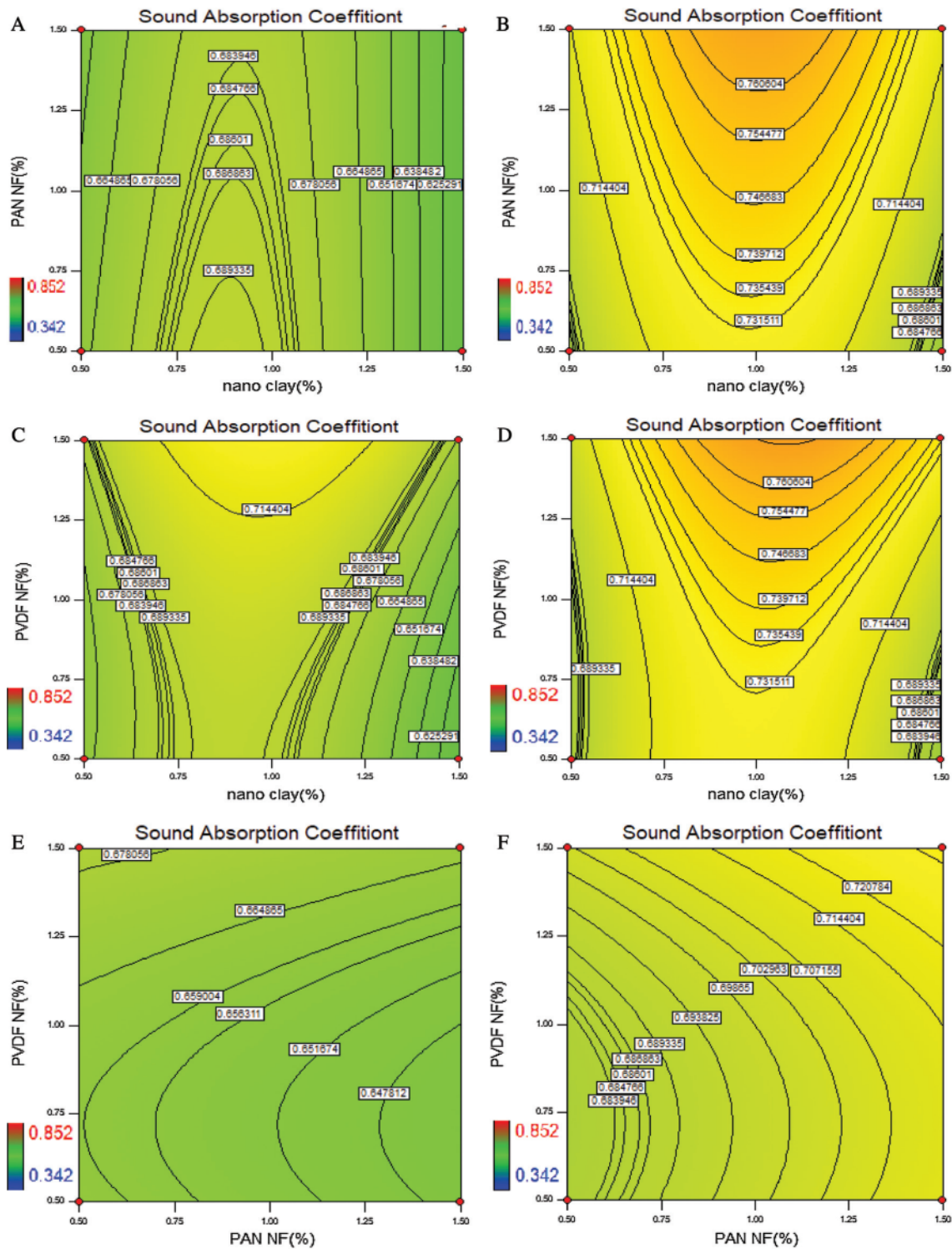
As shown in Fig. 6, and by comparing the right and left sides of Figs. 4 and 5, with increasing thickness, the rate of absorption coefficient grows both at low frequencies and at middle frequencies. A study by Wang et al. on the absorption properties of metallic fibers showed that with increasing thickness, the absorption coefficient increased [27], due to the losses caused by frictional losses [6]. Therefore, the sound energy is attenuated.

As revealed in Figs. 4 and 5, at the middle frequencies, in the case of using PAN NF and PVDF NF with the thickness of 1 cm, the sound absorption coefficient was maximum when PAN NF had the highest and PVDF NF had the lowest value. However, the simultaneous increase of PAN NF and PVDF NF at high frequencies at the same thickness did not have a considerable effect on increasing or decreasing the absorption coefficient. At the thickness of 2 cm, the increase in both nanofibers increased the absorption coefficient. At high and middle frequencies, in case of simultaneous use of clay nanoparticles and one of the nanofibers used (PAN NF or PVDF NF) at the thickness of 2 cm, the highest absorption time occurred when one of the nanofibers was maximum and the nano clay percentage lied with the range of 1%.

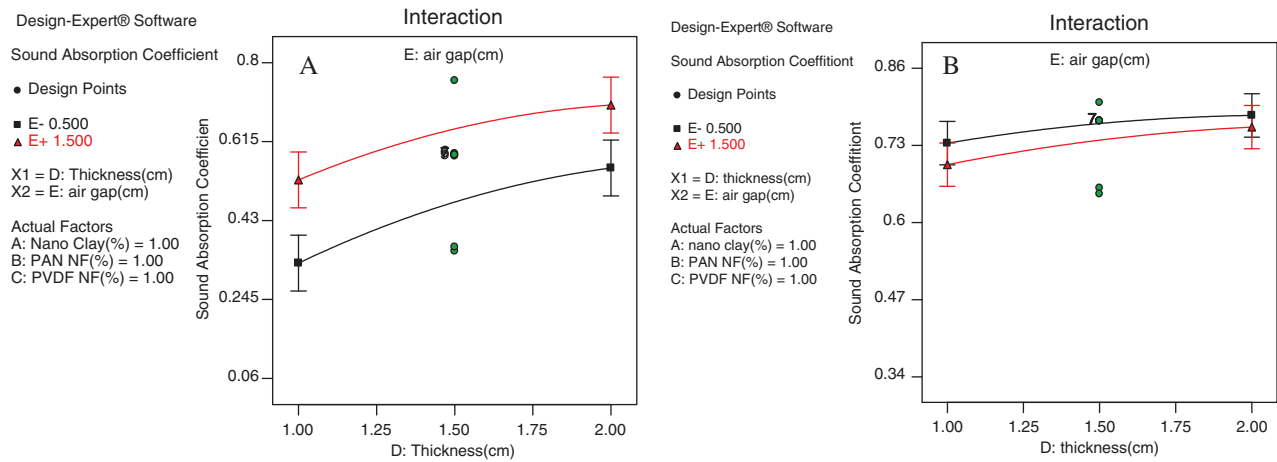
The sound energy in the fiber is absorbed through three physical processes: Initially, when the sound wave is introduced into the fiber, the viscose effect between the fiber structure and the various air cavities converts and dampens the part of the acoustic energy to the heat. Secondly, the heat transfer due to the



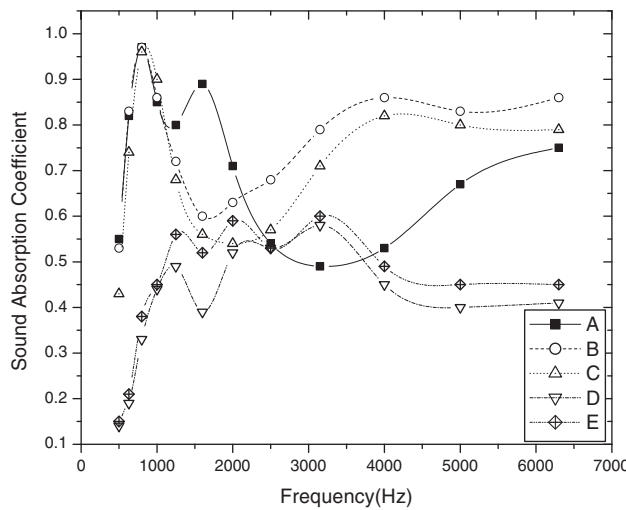
**Figure 4:** Effect of additives on the absorption coefficient of middle frequencies A: The effect of Nano Clay and PAN NF in a thickness of 2 cm and an air gap of 1.5 cm. B: The effect of Nano Clay and PAN NF in thickness of 1 cm and air gap of 1.5 cm. C: The effect of Nano Clay and PVD NF in thickness of 1 cm and air gap of 1.5 cm. D: The effect of Nano Clay and PVD NF in thickness of 2 cm and air gap of 1.5 cm. E: The effect of PAN NF and PVD NF in thickness of 1 cm and air gap of 1.5 cm. F: The effect of PAN NF and PVDF NF in thickness of 2 cm and air gap of 1.5 cm



**Figure 5:** Effect of additives on the absorption coefficient of the high frequencies A: The effect of Nano Clay and PAN NF in thickness of 2 cm and air gap of 1.5 cm. B: The effect of Nano Clay and PAN NF in thickness of 1 cm and air gap of 1.5 cm. C: The effect of Nano Clay and PVD NF in thickness of 1 cm and air gap of 1.5 cm. D: The effect of Nano Clay and PVD NF in thickness of 2 cm and air gap of 1.5 cm. E: The effect of PAN NF and PVD NF in thickness of 1 cm and air gap of 1.5 cm. F: The effect of PAN NF and PVD NF in thickness of 2 cm and air gap of 1.5 cm.



**Figure 6:** The effect of air gap and thickness on the absorption coefficient of sound. A: middle frequencies. B: high frequencies



**Figure 7:** Sound absorption coefficient of PU in combination with PAN NF, PVDF NF and clay nanoparticles. A: PU with 1.5% Nano Clay, PAN NF 0.5%, PVDF NF 0.5%, Thickness 1 cm, Air gap 1.5 cm. B: PU with 1.5% Nano Clay, PAN NF 0.5%, PVDF NF 1.5%, Thickness 2 cm, Air gap 1.5 cm. C: PU with 1.5% Nano Clay, PAN NF 1.5%, PVDF NF 0.5%, Thickness 2 cm, Air gap 1.5 cm. D: Pure PU with thickness of 1 cm, air gap 1.5 cm. E: Pure PU with thickness of 2 cm, air gap 1.5 cm

temperature differentiation between the various fibers causes a further deterioration of the air. The third vibration of the air into the mass of the material leads to the vibration of the fiber causing the sound waves to be damped [28]. Another feature that can affect the absorption coefficient is the Young modulus, as displayed in Fig. 7, which declines with the simultaneous increase of PAN NF and PVDF NF. The mechanical properties such the Young modulus can also affect the absorption coefficient. By reducing Young's modulus in porous materials, the absorption coefficient can be enhanced [29].

At the middle frequencies, when used together with nanoclay of clay and PVDF NF, at the thickness of 1 cm, the absorption coefficient was maximum where the nanoclay was the highest while the PVDF NF was



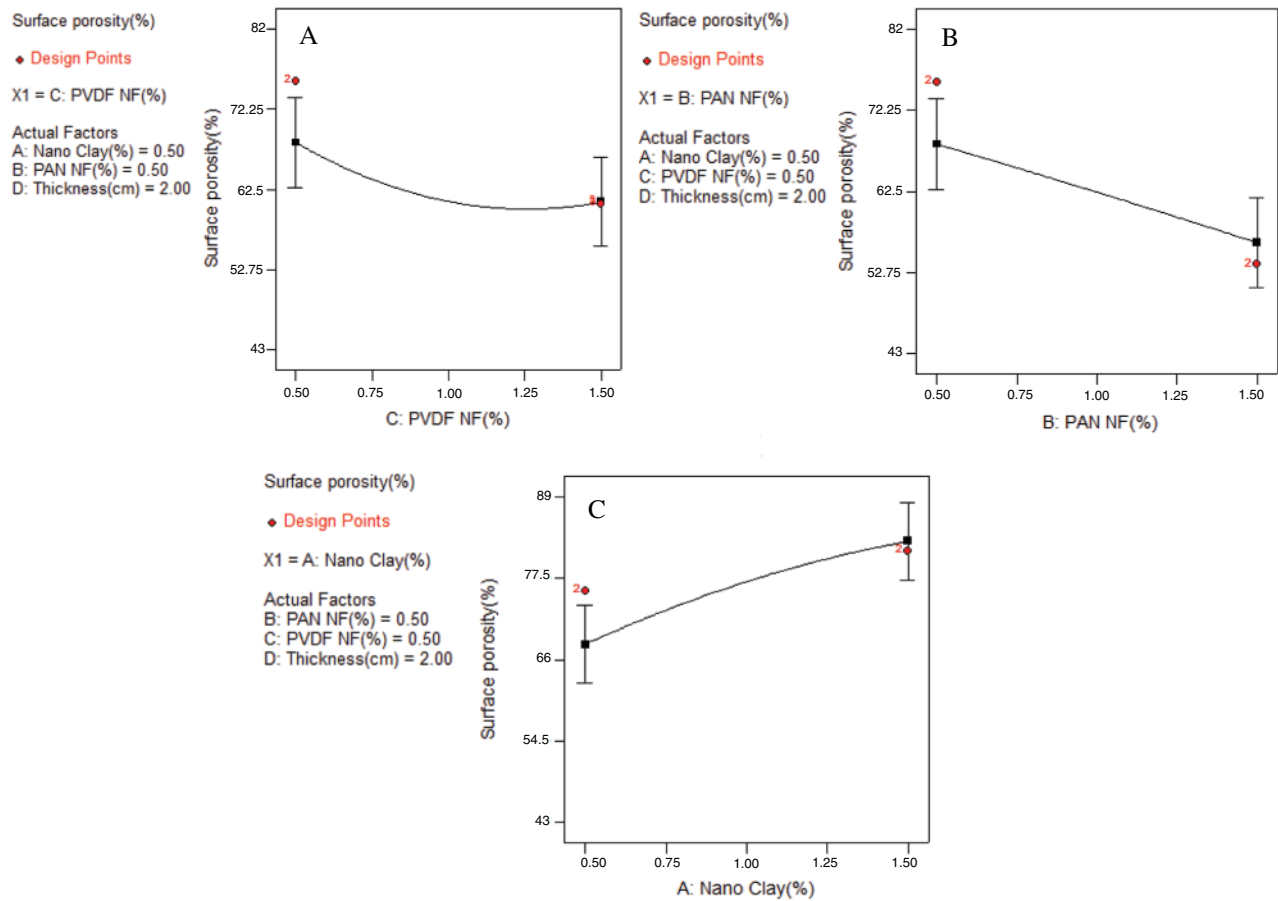
the lowest. However, at the thickness of 2 cm, the absorption coefficient at the highest, with PVDF NF highest and nano clay lying within the range of 1-1.5%. In the case of using clay nanoparticles and PAN NF at middle frequencies and thicknesses of 1 cm and 2 cm, the absorption coefficient was maximum when PAN NF was the highest and the nanoclay was less than 1%. However, at high frequencies at the thicknesses of 1 cm and 2 cm, in case of simultaneous use of nano clay and PVDF NF, as well as nano clay and PAN NF, the maximum sound absorption coefficient occurred when one of nanofibers had the highest value and nano clay lied within the range of 1%. These results and the observations of the researchers during the research indicated that nano clay may be moderately suitable; however, if used excessively, it may interfere with the structure and manner of foaming and even reduces the acoustic performance of the nanocomposite. As indicated in Fig. 4, at a thickness of 1 cm, at the middle frequencies, PAN NF had a greater effect on the elevation of the sound absorption coefficient. One of the reasons for the effect of PAN NF nanofibers at lower thicknesses than that of PVDF NF is that PAN NF has more fibers per unit volume due to its low density, and sound waves are also affected by the larger number of nanofibers at lower thicknesses whereby the sound energy is more damped. The results also suggested that with the rise of thickness, sound waves were affected by many nanofibers and further contributed to elevation of the absorption coefficient.

As displayed in Fig. 8, surface porosity increased with raising the nanoclay content, but the surface porosity diminished with increasing nanofiber. At low thicknesses, nanoparticles have a greater effect on the sound absorption coefficient compared to high thicknesses, but at high thickness of nanofibers, they have a greater effect on the absorption coefficient, especially at middle frequencies. This might be attributed to the fact that it is further affected by the increase of porosity at lower thicknesses. On the other hand at higher thicknesses, higher levels of nanofibers and fiber vibrations, due to collision of sound waves and increased damping, absorption is intensified and the nanoclay has less effect at lower thicknesses. Also, with elevation of nanofiber at higher thicknesses, sound traverses a more lenient path causing loss of sound energy by creating viscosity in the direction of the sound waves. Also, as shown in Fig. 8, with the rise of PAN NF and PVDF NF, the maximum absorption coefficient changed to low frequencies, making the absorption coefficient at middle frequencies larger than at high frequencies.

Figure 6 shows the effect of air gap and thickness on the absorption coefficient of sound at middle and high frequencies. As the air gap increased, the absorption coefficient rose at middle and high frequencies. The sound absorption coefficient is effective when the sample thickness of the porous material reaches one-tenth of the sound wavelength. The air gap at the back of the sample can help absorb the acoustic energy at middle and high frequencies; so as the air gap increases, the energy absorption of sound at increases long wavelengths [6, 30]. Also, by creating an air gap behind the absorber, the resonance phenomenon occurs at lower frequencies and results in better sound absorption at low frequencies [31].

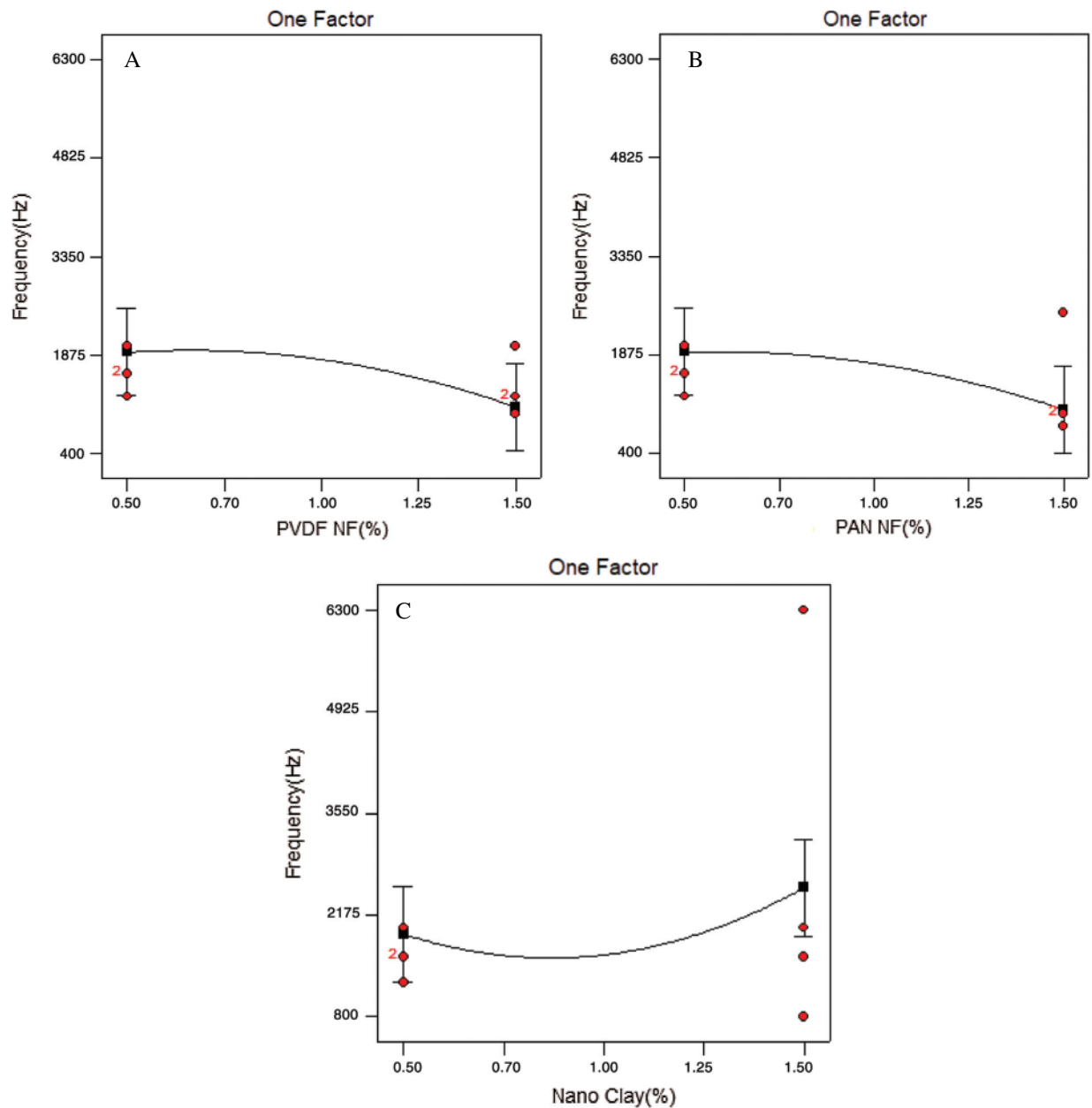
The average, maximum, and minimum porosity of composites was 62.24%, 81.39%, and 43.98%, respectively. The experimental run with the highest surface porosity showed a greater mean sound absorption coefficient. Fig. 8 reveals the effect of PAN NF, PVDF NF, and nano clay on surface porosity. With elevation of PAN NF and PVDF NF, surface porosity decreased, but with increasing nano clay, surface porosity increased. As shown in Fig. 8, in the two test runs, the absorption coefficient was the highest when nano clay was maximum. One of the reasons for the rise of the absorption coefficient in response to the increase of clay nanoparticles was the growth of porosity.

Figure 7 shows the graph of composites with a high absorption coefficient at the frequencies studied compared to pure PU with the same thickness and air gap. The highest absorption coefficient was found in the A compound 0.97 at 800 Hz. On the other hand, the highest absorption coefficient under the same conditions occurred in pure polyurethane 0.59 at 1250 Hz. A study by Büyükakinci et al. showed that using a fiber in PU, the maximum absorption coefficient occurred at lower frequencies [26].



**Figure 8:** Effect of nanoparticles and nano-fibers on surface porosity A: The effect of PVDF NF on surface porosity B: Effect of PAN NF on surface porosity C: Effect of nano clay on surface porosity

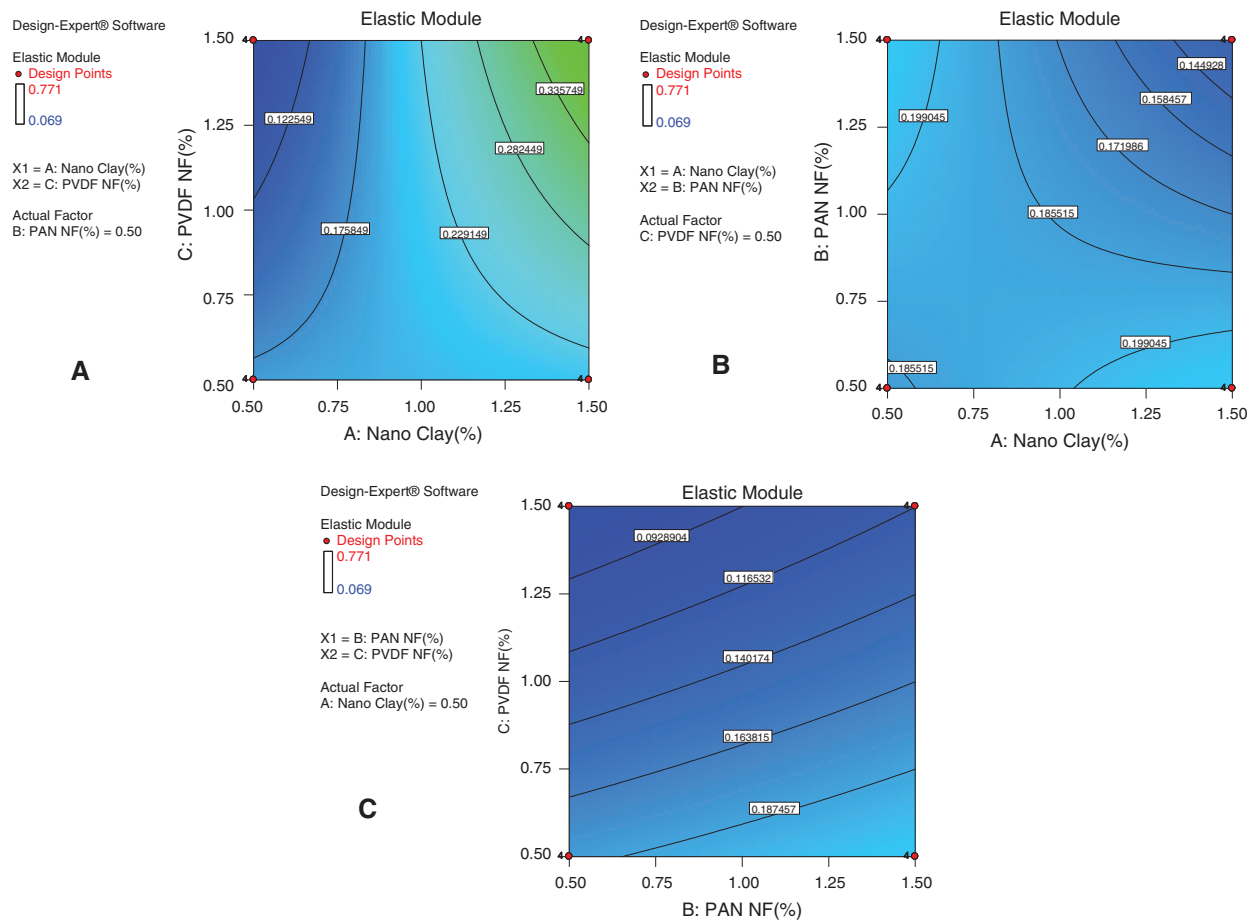
The average absorption coefficient at middle frequencies in composition A was 0.798 and 0.654, respectively, which improved 2.5 times at middle frequencies and 1.42 times at the high frequencies compared to pure PU under the same conditions. The highest absorption coefficient in the combination B and C was 0.97 and 0.96 occurring at the frequency of 800 Hz, respectively. On the other hand, the highest absorption coefficient in pure PU was 0.81 found at the same frequency of 1000 Hz. The average absorption coefficient in the combination of B and C at middle frequencies was 0.782 and 0.742, respectively, and at high frequencies, 0.75 and 0.684; compared to pure PU with air gap, and the thickness of 1.5 cm and 2 cm, the combination of B and C at middle frequencies showed increase in absorption coefficients by 2.23 and 2.12 times, respectively, at by 1.47 and 1.34 times at high frequencies. As displayed in Fig. 9, when using PAN NF, PVDF NF and nano clay, the maximum absorption coefficient shifted toward low frequencies. Compound A was a better fit for lower thicknesses and offered a better performance than others did. Intensified acoustic effect may be due to the high level of PU fillers, where acoustic energy can change into heat and decay. The formation of good morphology using fillers created more pathways for transmitting sound waves to the foam structure thereby absorbing more sound [32]. This study showed that in the case of simultaneous use of nano clay, PAN NF and PVDF NF, when nano clay and PVDF NF were the maximum and PAN NF was minimum, and also when PAN NF was the highest and PVDF NF and nano clay were the lowest,



**Figure 9:** The effect of nanoparticles and nano fibers on the frequency with the highest sound absorption coefficient A: PVDF NF B: PAN NF C: nano clay

the sound absorption coefficient became maximum. As PAN NF has a large volume due to its low density, and in case of using more PAN NF and more nano clay and PVDF NF, owing to the large volume of materials in the PU, foam formation, disruption, and the process of normal foam formation are impaired thereby affecting the absorption coefficient of the sound.

Figure 10 shows the effect of PAN NF, PVDF NF, and clay nanoparticles on the Young's modulus of flexible polyurethane foam. By increasing PAN NF and clay nanoparticles, as well as PAN NF and PVDF NF, the Young's modulus decreased. However, with elevation of PVDF NF and clay nanoparticles, the



**Figure 10:** The effect of nanoparticles and nanofibres on the Young's modulus. A: Effect of nano clay and PVDF NF. B: The Effect of Clay Nanoparticles and PAN NF. C: Impact of PAN NF and PVDF NF

Young's modulus increased. One of the reasons for the growth of Young's modulus can be creation of effective nuclear sites between fillers and the foam structure [33].

Table 1 present the ANOVA results of for Response Surface Reduced Quadratic Model. Table 2 reports the absorption sound models obtained at middle and high frequencies. In order to enhance the validity of the model at the middle frequencies, factors B2, E2, CE, BE and AD, which were not statistically significant, were eliminated from the model. To improve the validity of the model at high frequencies, factors AE, BC, CD and B2 were eliminated from the model. As shown in Tab. 1, the considered models were obtained at significant middle and high frequencies. Also, the lack of fit of models was obtained at both non-significant frequency ranges. These results suggest that the models obtained have had sufficient validity and can be effective in predicting the absorption coefficient in the middle and high frequency range. According to Tab. 1 and tests, the model confirmation has higher validity for middle frequencies than for the high frequencies.

Design-Expert software can be used to predict optimal combinations using input variables to reach the maximum, minimum, or specific value of the response variable. After obtaining the results, the sound absorption coefficient was optimized via this software. In order to optimize the software, the response variables were set in range. Tab. 3 provides some of the proposed solutions at different levels required for response variables with high absorption coefficient at low and middle frequencies.

**Table 1:** ANOVA for response surface reduced quadratic model

Frequency range	Source	Sum of Squares	df	Mean Square	F Value	P-value	
Middle Frequency	Model	1.23	17	0.072	4.98	0.0001	Significant
	Lack of Fit	0.42	25	0.017	2.90	0.0747	Not Significant
High Frequency	Model	0.16	16	0.00969	2.22	0.0258	Significant
	Lack of Fit	0.13	26	5.187E-003	2.74	0.0855	Not Significant

**Table 2:** The absorption sound models obtained at low and middle frequencies

Frequency range	Model	Equation
Middle Frequency	Quadratic	$\alpha = 0.56 - 0.016A - 0.0043B - 0.038C + 0.1D + 0.086E - 0.061AB - 0.043AC - 0.011AE - 0.041BC + 0.012BD + 0.047CD - 0.012DE - 0.059A^2 - 0.016C^2 + 0.032D^2$
High Frequency	Quadratic	$\alpha^* = +0.75 + 0.0003A^{****} + 0.00615B^{*****} + 0.019C^{*****} + 0.028D^{*****} - 0.014E^{*****} + 0.004AB + 0.011AC + 0.00975AD + 0.012BD + 0.002125BE + 0.002562CE + 0.004125DE - 0.052A^2 + 0.0091C^2 - 0.00965D^2 + 0.00685E^2$

Sound absorption coefficient\* \*\*A-nanoclay(%) \*\*\*B-PAN NF(%) \*\*\*\*C-PVDF NF(%) \*\*\*\*\*D-thickness(cm) \*\*\*\*\*E-Air Gap(cm)

**Table 3:** Some of the proposed solutions at low and middle frequencies

Frequency range	Nano clay (%)	PAN (%)	PVDF (%)	Thickness (cm)	Air Gap (cm)	Sound absorption coefficient
Middle Frequency	0.82	1.5	0.5	1.95	1.5	0.765
	0.74	1.5	0.5	1.94	1.5	0.764
High Frequency	1.09	1.5	1.49	2	0.5	0.823
	1.1	1.5	1.5	1.91	0.51	0.82

The regression equations and proposed software solutions were validated by developing and running two proposed solutions for each frequency range. The experimental tests were carried out and the values predicted by the model were evaluated. As reported in [Tab. 4](#), the absorption model in the middle frequency range was more reliable than in the high frequency domain model. The values of the various variables of the confirmatory tests, along with the predicted absorption coefficient have been presented in [Tab. 4](#) along with the difference of the observed percentages between the predictive values of the model and the experimental values.

**Table 4:** Comparing predicted and observed values

Frequency rang	Nano clay(%)	PAN (%)	PVDF (%)	Thickness (cm)	Air Gap	Sound absorption coefficient Predicted	Sound absorption coefficient observed
Middle	0.82	1.5	0.5	1.95	1.5	0.765	0.798
Frequency	0.74	1.5	0.5	1.94	1.5	0.764	0.794
High	1.09	1.5	1.49	2	0.5	0.823	0.775
Frequency	1.1	1.5	1.5	1.91	0.51	0.82	0.768

The mean of the difference in the sound absorption coefficient between the predicted and observed values in middle Frequency:4%  
The mean of the difference in the sound absorption coefficient between the predicted and observed values in high Frequency:6.4%

#### 4 Conclusion

This study indicated that the use of nano clay, PAN NF, and PVDF NF can improve the absorption coefficient of flexible polyurethane foam by more than twice at middle frequencies and more than 30% at higher frequencies. This improvement was due to the large surface area of nanoparticles and nano-fibers; elevation of the percentage of nano clay increased surface porosity and, at lower thicknesses, it had a greater effect on increasing the absorption coefficient of the sound absorption compared to PAN NF and PVDF NF at low thicknesses. This study also suggested that when using clay nanoparticles, PAN NF and PVDF, NF simultaneously, when nano clay and PVDF NF were maximum while PAN NF was minimum, and when PAN NF was maximum, PVDF NF and nano clay the lowest, absorption coefficient was maximum. In the case of concurrent application of nano clay, PAN NF and PVDF NF, the maximum absorption coefficient changed to low frequencies.

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